
DESKTOP AIR USER'S MANUAL

VERSION 4.0

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1. INTRODUCTION

1.1 OVERVIEW

DeskTop Air is an interactive air property calculator based on data published by the *National Bureau of Standards* (NBS) in 1955 (1). The NBS data is also the basis of the formulations used to develop the tables published in the *American Society of Heating, Refrigeration and Air-Conditioning (ASHRAE) Fundamentals*, 1993. All of the properties calculated by *DeskTop Air* are based on real gas properties, not perfect gas approximations. As such, they include the effects of pressure and interactions caused by the mixing of water vapor and dry air components. Details on the theory and accuracy are provided in this user's manual.

The psychrometric properties facilitate conversion among various moist air parameters such as absolute humidity, relative humidity, wet bulb temperature and degree of saturation. The thermodynamic properties provide forward and inverse relationships using specific volume, specific enthalpy and specific entropy. The transport properties provide specific heat, dynamic viscosity and thermal conductivity from pressure, temperature and humidity ratio.

The *DeskTop Air* functions are valid over a temperature range from 180 °K, (-136 °F) to 2000 °K, (3140 °F) and at pressures up to 5.0 MPa, (725 psia). The functions detect requests for calculations outside that range and return an error value.

1.2 32-BIT AND 64-BIT VERSIONS

The *DeskTop Air* package includes both 32-bit and 64-bit installation files. If you are running a 64-bit operating system, such as Windows 7, you should install the 64-bit version; otherwise you should install the 32-bit version. They are functionally identical.

2. USING DESKTOP AIR

2.1 OVERVIEW

DeskTop Air is a Windows application, which calculates the thermodynamic and transport properties of moist air. It can be used as an interactive replacement for air property tables and psychrometric charts but does much more than that. It automatically calculates all unknown properties when a state point is defined by known properties. The program is flexible, and designed to minimize keystrokes for common calculations. *DeskTop Air* allows you to enter any number of state points, label them and store the collection of points for later reference. You can print a table of stored points or copy them to the clipboard and paste them into your favorite spreadsheet or word processor.

Major features of this program include:

- validity over a wide range of pressures and temperatures
- flexible interactive design
- large choice of units for each property
- tools for heating, cooling, expansion and compression processes
- instant response time
- extensive help screens

If installed properly, *DeskTop Air* is started by simply double clicking on its name/icon in the *DeskTop Air* subgroup of the *TechwareEng* Group appearing in the Windows Start Menu.

2.1.1 Valid Operating Range

The *DeskTop Air* functions are valid over a temperature range from 180 °K, (-136 °F) to 2000 °K, (3140 °F) and at pressures up to 5.0 MPa, (725 psia). The functions detect requests for calculations outside that range and return an error value.

2.2 BASIC OPERATION

The *DeskTop Air* display is arranged in a tabular format that remains constant although the program window can be re-sized. You may sometimes find it convenient to make the program window smaller. Each of the rows is dedicated to one of the air properties (pressure, dry bulb temperature, specific volume, enthalpy, entropy, wet bulb temperature, dew point, relative humidity, humidity ratio, degree of saturation, H₂O mole fraction, H₂O mass fraction, molecular mass, specific heat, dynamic viscosity and thermal conductivity). There is a column that displays the property values for the active point and a column that displays data for one of the stored points.

The key properties that can be used to define the air state point are: pressure, temperature, specific volume, enthalpy, entropy, and one of the moisture indicators. Theoretically, a state

point can be uniquely identified by specifying the moisture content and any two of the other five properties. On a Psychrometric chart, the state point is normally determined as the intersection of two lines, which represent two variables. Only two values are required on the Psychrometric chart because the chart is valid for only a single air pressure. In most practical applications, pressure is usually one of the known variables. Most of the calculations require that the pressure be known. In the rare case when pressure is not known, it can be calculated from the equation of state if the dry bulb temperature, specific volume and humidity ratio is known.

Each of the key properties has a check box associated with it. When checked, it signifies that this property is to be used in calculating the state point. In general, two thermodynamic properties and one other property, which indicates the moisture content, must be selected before *DeskTop Air* will allow a computation. There are some combinations of only two properties that allow computation in the saturated state. In these cases, you will notice that the 'Compute Saturated' button is enabled. Once you select one property, *DeskTop Air* will disable all the other check boxes whose properties are not allowed in combination with the first selected property. You may change your selections by un-checking one or all of the check boxes and selecting a new combination.

To compute an air property state point, begin by selecting the input properties and set the corresponding check boxes as described above. Enter values for those properties in the boxes to the right of the property names. (The next section describes various methods for entering data.) When you enter a value for any of the key properties, a red "X" appears next to the property value to indicate that a new value has been entered. This is a warning that the value being displayed is not consistent with the current state point. After a compute command is completed successfully, all property values are recalculated and the red "X's" are cleared.

Be sure to enter the values in units consistent with the unit displayed to the right of the value box. If you wish to change units, select the desired units before entering the value. If you change units after the value is entered, the value entered will be converted to the new units.

Next, click the 'Compute' button to find all the unknown properties. If the 'Compute' button is grayed, you have not checked enough properties to define the state point. Fields without check boxes are output only. These include molecular mass, specific heat, viscosity and thermal conductivity. After recalculation, all fields contain property values for moist air at a particular state point.

The box labeled "Reference" identifies the reference conditions for the property values. It indicates whether the values are on a wet or dry basis, the reference pressure for entropy and the reference temperature for dry air enthalpy and entropy.

2.2.1 Wet or Dry Basis

All mass-dependent properties (specific volume, enthalpy, entropy, specific heat, viscosity and conductivity) can be based on either a dry or wet basis. The default for *DeskTop Air* expresses the properties per mass of dry air. This is consistent with ASHRAE conventions and is quite useful when dealing with processes that involve evaporation or condensation of water vapor.

In some cases, you may wish to express these properties on a wet basis, that is, per mass of

wet air (dry air plus water vapor). You can accomplish this by selecting 'Ref' from the Toolbar or 'Reference Conditions' from the 'Tools' menu.

2.2.2 Reference Conditions

Enthalpy and entropy values are always expressed relative to particular reference conditions. Many people forget that the values of enthalpy and entropy that are found in published tables are not absolute values but instead, are relative to particular reference conditions. Engineering calculations always deal with enthalpy or entropy differences, typically between in-flowing and out-flowing streams. For this reason, it does not matter what you select as the reference conditions, as long as you use them consistently. *DeskTop Air* allows you to select reference conditions consistent with ASHRAE or an alternate set of conditions based on absolute zero temperature.

In SI units, ASHRAE uses a reference condition of 0 °C and one atmosphere of pressure for dry air. For water vapor, ASHRAE used a reference condition of liquid water at the triple point temperature of 0.01 °C. In English units, however, ASHRAE uses a reference condition of 0 °F at one atmosphere of pressure for dry air properties while maintaining the convention of using the triple point as a reference temperature for water properties. *DeskTop Air* allows you to set the reference temperature of 0 °F, 0 °C or 0 °K.

Please note that in all cases, the enthalpy and entropy of the water portion are set to zero for liquid water at the triple point temperature. Some publications, which are based on perfect gas assumptions, assign the zero point for enthalpy and entropy to water in the vapor state at the triple point or some other specified temperature. We believe that setting the zero point for enthalpy and entropy to water in the liquid state rather than in the vapor state has two major advantages. First, the values are numerically equivalent to standard international steam tables (and Techware's **WinSteam** product). This facilitates the handling of processes that include both moist air and liquid water streams without worrying about reference temperatures. Second, It greatly simplifies analysis of processes in which water is either condensed from or evaporated to the air stream.

All reference conditions use the International Temperature Scale of 1990 (ITS-90) described in reference (5) as the basis of temperature.

2.3 ENTERING DATA

Numeric data is entered in a specially designed edit box called an IO Box, which behaves like a standard Windows edit box but includes some additional features. To enter new data, double click the IO Box and all the data will be highlighted. As you enter new data, the old data will be replaced. To edit data, hold the left mouse button down and drag the mouse over the characters that you wish to replace, thereby highlighting them. Release the mouse button and type new characters to replace the highlighted ones.

The IO Box has two modes of operation, input and output. When new data is entered, the IO Box is placed in the input mode and a red X appears to the left of the box. After a new state point is computed, all IO Boxes are placed in the output mode and the red X's are removed.

The IO Box accepts either numerical values or arithmetic expressions that can be evaluated to a numeric value. A number can be entered in either decimal or scientific notation. The expression can be any valid arithmetic expression using the following operators:

+	add
-	subtract
*	multiply
/	divide
^	exponent
()	parentheses

Arithmetic calculations can be nested to any level using parentheses. An example of a valid expression is:

$$((1004^2 + 997^2) / 2)^.5$$

which evaluates to 1000.506.

Expressions are evaluated whenever you tab to or click on another control or press the 'Enter' button. Only the resulting value is shown in the box. If you enter an incorrect expression, your computer will beep and the edit cursor will highlight the offending character. You must fix the error before *DeskTop Air* will allow you to continue.

If the expression you are entering is too long to fit in the box, the box will temporarily increase in length so that you may view more of the expression. When you are finished editing, the box returns to its original length.

To recall the last expression used in an input box, use the 'Recall Expression' command on the 'Edit' menu. You'll then have the opportunity to edit the expression and let the IO Box re-evaluate it. Note that the box retains the last number or expression entered even after a compute command is issued. As a result, the value in the box will not reflect the value of the recalled expression if a compute command has altered the value.

You may use the 'Cut', 'Copy' and 'Paste' commands on the 'Edit' menu or the toolbar to exchange numeric data between *DeskTop Air's* IO Boxes and any other application that supports the clipboard. If you start entering data in an IO Box and wish to go back to the original data you may use the 'Undo' command on the 'Edit' menu. However, once the IO Box loses the focus, the 'Undo' command is no longer available.

2.4 UNIT SELECTION

DeskTop Air allows you to use any combination of units for input and output properties. The units for each property can be set independently by using its associated combo box. To change a unit, select its combo box and scroll through the list of available units using either the keyboard cursor arrows or the mouse. Whenever a new unit is selected, the program converts the values displayed for that property to the new units. Therefore, when entering data you should first select the units and then key in the input values. Otherwise, the values will be converted to the new units and you will have to re-enter them.

The first time the program is started, the properties will be displayed in SI units. You can change all of the units to either standard English or SI units by issuing the 'English Units' or 'SI

Units' command from the 'Format' menu or pressing the 'Eng' or 'SI' toolbar button. When you change to English units in this manner, the reference temperature for dry air is changed to 0 °F. Similarly, when changing to SI units, the reference temperature is changed to 0 °C.

You may choose any combination of available units for your default unit set. Simply select the units you desire for each property and issue the 'Make Current Settings Default' command from the 'Format' menu. The next time you start *DeskTop Air*, your default unit set will be used.


If you change units and then save a file, those selected units will be restored whenever the file is opened. If you wish to change the units back to your default unit set, issue the command 'Restore Default Settings' from the 'Format' menu.

2.5 CALCULATING STATE POINTS

When you have finished entering values for the selected input variables, click the on-screen button labeled 'Compute' to calculate all of the state point properties. If the 'Compute' button is grayed, you have not checked enough properties to define the state point.

You may also compute the state point by pressing the 'Enter' key on your keyboard. Note that the 'Enter' key serves two purposes in *DeskTop Air*. Pressing the 'Enter' key just after entering data in an IO Box, tells *DeskTop Air* to evaluate the expression in the IO Box. Pressing the 'Enter' key a second time tells *DeskTop Air* to compute the state point. If you move the focus to any other control after entering data in an IO Box, the expression is evaluated automatically and you only have to press the 'Enter' key only once to compute the state point. The 'Enter' key will not compute a state point if the 'Compute' button is grayed.

2.6 FORMATTING PROPERTY VALUES

DeskTop Air normally displays all property values in fixed decimal notation. You may increase or decrease the number of decimal places in a selected property IO Box by selecting 'Add Decimal Places' or 'Decrease Decimal Places' from the 'Format' menu or by clicking either of the  toolbar buttons, respectively.

If you wish to change the selected property to scientific notation, select the 'Scientific Notation' command from the 'Format' menu or press the 'EE' toolbar button. The 'Format' menu may be used to change the number format to 'Fixed Decimal' or 'Percent' as well. Corresponding toolbar buttons are 'Fix' and '%' respectively. Of course, the percent format only makes sense for the non-dimensional properties.

The formatting commands are only enabled when the focus is on an IO Box.

2.7 LABELING AND STORING STATE POINTS

DeskTop Air gives you the option of labeling and storing any number of state points for future reference. After computing the state point, *DeskTop Air* will automatically suggest a unique name for the new state point such as Point 1 or Point 2, but you will probably want to enter something more descriptive. Just enter a new name in the Point Label box.

To store this point, press the 'Store Point' button. (The Store button will not be enabled if the displayed data is not a correctly calculated state point.) *DeskTop Air* requires all stored points to have a unique label. If you try to store two points with the same label, *DeskTop Air* will query whether you wish to replace the stored point, which has the same label, with the current point. If not, you should rename the point and try to store it again.

After storing the point, the state point values for the active point will be copied into a storage array and given the name you selected. The point will be displayed in the stored points column in same units as the active point. After a state point is stored, its name is added to the point name combo box in the upper right hand corner of the main window. You can view a stored point by pressing the arrow on the point name combo box and selecting a point from the drop down list.

If you wish to use a stored point with any of the special tools or as the basis for calculating a new point, you must recall the stored point to the active point. Begin by selecting the point from the point name combo box's dropdown list. Next, press the 'Recall Point' button to copy the stored point to the active point. You may now use the active point for new calculations. If you change any input data and press 'Compute', the active point will be changed but the stored point from which you copied the values will remain intact.

You can delete a stored point by first selecting it from the Point Name combo box and then select 'Delete Point' from the 'Edit' menu.

This collection of state points can be saved as a *DeskTop Air* file. In addition, you can copy state points to the clipboard, where they can be transferred to another application such as a spreadsheet program or word processor.

2.8 PRINTING

You can print a table consisting of all of the stored points by selecting the Print command from either the file menu or the toolbar. The tables will include a column for each of the stored points with each of its properties listed in a row. A label for each row includes the property name and the current units selected. The printing utility will attempt to fit as many points on a page as possible, based on the paper size and orientation that you specify using the 'Print Setup' command. You can preview the output by selecting the 'Print Preview' command from the 'File' Menu.

2.9 SAVING AND OPENING DATA FILES

When you start *DeskTop Air* or open a new file, it will be untitled. You may save a collection of stored state points along with your selections of units and formats to a *DeskTop Air* file. Select 'Save' from the 'File' menu or click the disk icon on the toolbar, which will open the "Save As" dialog box. You should enter a name for the file; the file extension ".air" will be added automatically. You may choose a folder in which to save the file or accept the default folder.

If you have saved the file at least one time during the session, you can save the work under a different filename by choosing the 'Save As' command from the 'File' menu.

To open a saved file, select 'Open' from the 'File' menu or click the open file icon on the

toolbar. This will open a dialog box that lists all of your *DeskTop Air* data files in the current folder. You may select a different folder to view other files. Select the file you want to open and press the 'Open' button to load the file.

To start a new file, select the 'New' button from the Toolbar. If you have stored any points and have not saved the file, you will be prompted to do so.

2.10 ADVANCED FEATURES

DeskTop Air includes special tools that facilitate the calculation of some common air processes. These tools include an expansion/compression tool and a heating/cooling tool.

2.10.1 Expansion/Compression Tool

The Expansion/Compression tool is used to evaluate performance of an air turbine or an air compressor. If you are predicting the performance and know the efficiency of the turbine or compressor, the tool can be used to calculate the state point conditions at the expansion or compression end point. If you are analyzing the performance of a turbine or compressor and know the conditions at the end point, the tool can be used to calculate the efficiency. The tool also computes the energy converted to shaft work generated by the turbine or used by the compressor.

To use the tool, first select the active state point representing the start of the expansion or compression path. Next, select 'Expand/Compress' from the 'Tools' menu or click the turbine icon on the toolbar, which will open the Expansion/Compression tool dialog box.

In the tool dialog box, select the conditions you will use to compute the end point from the combo box near the top of the screen. Select "Pressure & Efficiency" if you know the pressure and efficiency. If you are checking an actual machine you will need to know the exiting air temperature or enthalpy. Check either the "Pressure, Enthalpy" or "Pressure, Temperature" buttons as required. The two variables you have chosen will have their value fields enabled; all others will be grayed. Enter the appropriate values and click the 'Compute' button.

The "Air Flow In" column displays the state point properties entering the equipment, which were copied from the active point. The "Total Flow Out" box has three columns that display the state point properties at the end of the expansion. The first column identifies the thermodynamic properties for the mixture of moist air and liquid water exiting the equipment. The second column displays the thermodynamic properties for the moist air exiting and the third column shows the properties for the liquid water if any condensation occurs. The units displayed are those currently in use on *DeskTop Air's* main window. If you wish to use different units, you should select those units on the main window before opening the expansion tool.

Below the state point properties, you will find the shaft power based on the entering air flow rate that you entered. The units for these results will be consistent with your input units.

You may change any of the data and repeat the calculation as required. When you are satisfied with the result, you may copy that state point back to the active point on *DeskTop Air's* main window by pressing the 'OK' button. Note that the values of moist air in the second column will be copied back to the active point. If no condensation has occurred, these values

will be the same as in the first column labeled mixture. If condensation has occurred, then the values in the second column will be at saturated conditions.

If you do not wish to replace the current point on the main window with the expansion end point calculated, just press the 'Cancel' button.

2.10.2 Heating/Cooling Tool

The Heating/Cooling tool is used to analyze an air stream in which heat is either added or removed. If you know the quantity of heat that is being added to or removed from the air stream, you can use the tool to calculate the resulting state point temperature and other conditions. If you know the temperature or enthalpy of the air leaving the heating or cooling device, you can use the tool to calculate the quantity of heat exchanged.

To use the tool, first make sure that the active state point represents the conditions of the air entering the heating or cooling device. Next, select 'Heat/Cool Tool' from the 'Tools' menu or click the flame icon on the toolbar, which will open the Heating/Cooling tool dialog box.

In the tool dialog box, select the conditions you will use to compute the end point from the combo box near the top of the screen. Select "Pressure, Heat Flow" if you know the pressure and heat added or removed. If you are measuring performance on an existing device you will need to know the exiting air temperature or enthalpy. Check either the "Pressure, Enthalpy" or "Pressure, Temperature" buttons as required. The two variables you have chosen will have their value fields enabled; all others will be grayed. Enter the appropriate values and click the 'Compute' button.

The "Air Flow In" column displays the state point properties entering the equipment, which were copied from the Active Point in the main screen window. The "Total Flow Out" box has three columns that display the state point properties at the end of the expansion. The first column identifies the thermodynamic properties for the mixture of moist air and liquid water exiting the equipment. The second column displays the thermodynamic properties for the moist air exiting and the third column shows the properties for the liquid water if any condensation occurs. The units displayed are those currently in use on *DeskTop Air's* main window. If you wish to use different units, you should select those units on the main window before opening the Heating/Cooling tool.

Below the state point properties, you will find the heat added based on the entering airflow rate that you entered. The units for these results will be consistent with your input units.

You may change any of the data and repeat the calculation as required. When you are satisfied with the result, you may copy that state point back to the Active Point on *DeskTop Air's* main window by pressing the 'OK' button. Note that the values for moist air in the second column will be copied back to the active point. If no condensation has occurred, these values will be the same as in the first column labeled mixture. If condensation has occurred, then the values in the second column will be at saturated conditions.

If you do not wish to replace the Active Point on the main window with the heating/cooling state point calculated, just press the 'Cancel' button.

2.10.3 Exchanging Data with Other Programs

DeskTop Air includes two ways to share data with other applications running on your PC such as Excel. Both methods use the Windows clipboard.

In the first data sharing method, *DeskTop Air*'s 'Edit / Copy' command copies whatever text is highlighted in an IO Box (e.g., a number or part of a number) to the Windows clipboard. From there, that text can be pasted into other applications running on your PC. This is typically done using those applications' 'Edit / Paste' command).

The second data sharing method also places text on the clipboard but uses an extended format that is especially useful for calculations involving air properties. This method is accessed using the 'Copy Point' command on the 'Edit' menu. Regardless of whether any text is selected, this command copies a *table* of text values to the clipboard using either the Active Point or all of the stored points. The table includes one column for each point. You can optionally direct *DeskTop Air* to also include property and unit labels in which case they appear as the first column in the table. The table includes one row for each property in the same order as they are displayed on *DeskTop Air*'s main window. All values are copied to the clipboard using the same format displayed on the screen. So, if you need more accuracy in your Excel calculations, set the *DeskTop Air* display accuracy accordingly, before issuing the 'Copy Point' command.

2.11 GETTING HELP

The Help menu offers extensive on-line help for *DeskTop Air*. The 'About' item in the Help menu presents the version and serial numbers of your copy of @Air.

2.12 ERROR MESSAGES

When input values are out of range or any other errors occur, a message box is displayed describing the error. The calculated fields will not be updated until the error condition is resolved.

2.13 EXITING DESKTOP AIR

You may exit *DeskTop Air* by using any of the standard methods for closing Windows applications. These include the following:

- Click the upper left corner of its program window and select close from the menu.
- Select Exit from the File menu.
- Press Alt + F4 keys.
- Click the "X" button in the upper right corner of the program window

3. THEORETICAL BASIS OF @AIR FUNCTIONS

3.1 BASIS OF CALCULATIONS

The formulations used in developing the air property functions treat moist air as a mixture of two real gases, namely, dry atmospheric air and water vapor. Furthermore, dry atmospheric air is assumed to be a homogeneous, single-component gas with an apparent molecular weight of 28.9645 g/mol.

The P-V-T behavior of the mixture is described by a virial equation of state:

$$\frac{P\bar{v}}{RT} = 1 + \frac{B_m}{\bar{v}} + \frac{C_m}{\bar{v}^2} + \dots$$

where,

P = Total pressure

T = Absolute Thermodynamic Temperature

\bar{v} = Total volume of gas

R = Universal Gas Constant

B_m = second order virial coefficient of the mixture

C_m = third order virial coefficient of the mixture

For the ranges of pressure and temperature used in these functions, the higher order coefficients can be ignored. It can be shown for the air-water mixture that

$$B_m = x_a^2 B_{aa} + 2x_a x_w B_{aw} + x_w^2 B_{ww}$$

and

$$C_m = x_a^3 C_{aaa} + 3x_a^2 x_w C_{aaw} + 3x_a x_w^2 C_{aww} + x_w^3 C_{www}$$

where,

x_a = mole fraction of air in the mixture

x_w = mole fraction of water in the mixture

B_{aa}, C_{aaa} = virial coefficients of air

B_{ww}, C_{www} = virial coefficients of water vapor

B_{aw}, C_{aaw}, C_{aww} = virial coefficients of the mixture

ASHRAE uses polynomial equations for estimating the virial coefficients of air and water vapor as presented by Hyland and Wexler [8]. These equations are derived from the data presented by the NBS [1]. While these equations produce reasonable results, they are limited in temperature range from about -100 °C to 200 °C and are clearly inadequate for this application, which supports temperatures up to 2000 °K.

Instead of using polynomial equations, Techware has developed a gas property database from the NBS [1] data. The database includes virial coefficients as well as ideal gas properties for enthalpy, entropy and specific heat that span the range of temperatures from 180 °K to 2000 °K. Coefficients are extracted from the database at any desired temperature using non-linear interpolation.

The molar enthalpy of moist air, h_m can be described by the equation

$$h_m = x_a(h_a^o + h_a') + x_w(h_w^o + h_w') + RT \left[\left(B_m - T \frac{dB_m}{dT} \right) \frac{1}{\bar{v}} + \left(C_m - \frac{1}{2} T \frac{dC_m}{dT} \right) \frac{1}{\bar{v}^2} \right]$$

where,

h_a^o = ideal gas molar enthalpy for air

h_w^o = ideal gas molar enthalpy for water

h_a' = constant to adjust reference state for air

h_w' = constant to adjust reference state for water

The molar entropy of moist air, s_m can be described by the equation

$$s_m = x_a(s_a^o + s_a') + x_w(s_w^o + s_w') - R \ln P + x_a R \ln \left(\frac{P\bar{v}}{x_a RT} \right) + x_w R \ln \left(\frac{P\bar{v}}{x_w RT} \right) - R \left[\left(B_m - T \frac{dB_m}{dT} \right) \frac{1}{\bar{v}} + \frac{1}{2} \left(C_m - T \frac{dC_m}{dT} \right) \frac{1}{\bar{v}^2} \right]$$

where,

s_a^o = ideal gas molar entropy for air

s_w^o = ideal gas molar entropy for water

s_a' = constant to adjust reference state for air

s_w' = constant to adjust reference state for water

The molar specific heat at constant pressure of moist air, c_m , can be described by the equation:

$$c_m = c_a^o x_a + c_w^o x_w - R - \frac{RT}{v} \left(2 \frac{\partial B_m}{\partial T} + T \frac{\partial^2 B_m}{\partial T^2} \right) - \frac{RT}{2v^2} \left(2 \frac{\partial C_m}{\partial T} + T \frac{\partial^2 C_m}{\partial T^2} \right) + \frac{R \left(1 + \frac{B_m}{v} + \frac{C_m}{v^2} + \frac{T}{v} \frac{\partial B_m}{\partial T} + \frac{T}{v} \frac{\partial C_m}{\partial T} \right)}{1 + \frac{2B_m}{v} + \frac{3C_m}{v^2}}$$

where,

c_a^o = ideal gas molar specific heat of dry air at constant pressure

c_w^o = ideal gas molar specific heat of water vapor at constant pressure

For combinations of pressure and temperature below the boiling point of water, there is a maximum quantity of water that can exist at that temperature in the vapor state. In this condition, the air is said to be saturated. For the case where moist air exists in a saturated state, the mole fraction of water vapor, x_{ws} is given by

$$x_{ws} = \frac{fp}{P}$$

and the mole fraction of air, x_{as} is given by

$$x_{as} = \frac{P - fp}{P}$$

where,

p = the pressure of saturated vapor over pure condensed phase ice or water.

f = a dimensionless quantity introduced by Goff (1949) called the enhancement factor or excess solubility, which is equal to $x_{ws} / x_{wsideal}$.

$x_{wsideal}$ = the ratio of the vapor pressure of the pure water, to the total pressure of the mixture.

ASHRAE uses equations for estimating the enhancement factor as well as the virial coefficients of dry air and air/water mixture developed by Hyland and Wexler [8]. This version of *DeskTop Air* uses another method for calculating the enhancement factor presented by Rabinovich [3]. We believe that this method produces better correlation with the original experimental data developed by Goff. Even so, the differences between the two methods are generally small.

Assuming that the condensed phase is pure water, the value of x_{ws} can be found by equating the chemical potential of pure condensed water with the chemical potential of its vapor in the gas solution. Since the equations describing chemical potentials are non-linear and difficult to analyze, phase equilibrium is often described in terms of a thermodynamic function called fugacity. The equality of chemical potentials can be replaced by equating the logarithms of the fugacity of pure condensed water with that of its vapor in the gas mixture solution. The equation of solubility based on this concept is derived by Rabinovich [3] and can be expressed as follows:

$$\ln \frac{x_{ws} P}{p_{ws}} = \ln \frac{z(p, T, x_{ws})}{z_w(p_{ws}, T)} + \frac{1}{RT} \int_{p_{ws}}^p v_{wcond} dp + \frac{2B_{ww}}{v_w''} + \frac{3C_{www}}{2(v_w'')^2} - \frac{2}{v} (B_{aw} + (B_{ww} - B_{aw})x_{ws}^2) - \frac{3}{2v^2} (C_{aaw} + 2(C_{aww} - C_{aaw})x_{ws} + (C_{aaw} - 2Ca_{gww} + C_{www})x_{ws}^2)$$

where,

$$z = 1 + \frac{B}{v} + \frac{C}{v^2} \quad \text{the compressibility of the air mixture or the water vapor as required.}$$

p_{ws} = saturation pressure of water vapor at temperature T.

v_{wcond} = the volume of the condensed water.

The solubility equation can be solved for x_{ws} by iteration. The value of x_{ws} is used to find the dew point temperature of a gas mixture, to determine the amount of condensation that occurs in a cooling process and to verify that the value of x input by the user does not exceed x_{ws} .

3.2 HUMIDITY PARAMETERS

In determining the thermodynamic properties of moist air, it is required to know the relative quantities of water vapor and dry air in the mixture. The formulations described above use the mole fractions of air and water for this purpose. In practice, it is common to use other parameters as well to define the proportions of air and water vapor in the mixture. The most common of these parameters include humidity ratio, relative humidity, degree of saturation, wet bulb temperature and dew point temperature and mass fraction of water vapor. *DeskTop Air* allows you to input any of the various parameters for determining the level of moisture in the air and displays all of the others when the state point is calculated.

The definitions of each moisture parameter are as follows:

$$\text{Humidity Ratio} = \frac{M_w}{M_a}$$

where,

M_w = mass of water vapor in sample

M_a = mass of dry air in sample

As described in section on alternate moisture parameters, mole fraction or mass fraction of water vapor can be substituted for humidity ratio through the unit set argument.

$$\text{Relative Humidity} = \frac{x_w}{x_{ws}}$$

where,

x_w = mole fraction of water vapor

x_{ws} = mole fraction of water vapor saturated at the same temperature and pressure

$$\text{Degree of Saturation} = \frac{W}{W_s}$$

where,

W = humidity ratio

W_s = humidity ratio of saturated air at the same temperature and pressure

Dew Point Temperature (D) is defined as the solution to the equation:

$$W_s(P, D)_s = W$$

It represents the temperature to which a sample of moist air at a given unchanging pressure can be cooled before condensation begins.

Thermodynamic Wet Bulb Temperature (B) is the temperature at which water, by evaporating into moist air at a given dry-bulb temperature and humidity ratio, can bring the air to saturation adiabatically at the same temperature B while the pressure is maintained constant. It is defined as the solution to the equation:

$$h(P, T, W) + [W_s(P, B) - W(P, T)]h_w(B) = h_s(P, B)$$

where,

$h(P, T, W)$ = enthalpy of the moist air sample at given pressure, dry bulb temperature and humidity ratio.

h_w = enthalpy of water added at the wet bulb temperature.

$h_s(P, B)$ = enthalpy of saturated air at the wet bulb temperature.

3.3 TRANSPORT PROPERTIES

Values for viscosity and thermal conductivity of dry air at atmospheric pressure can be found in many references although there does not appear to be any definitive standard of accepted values as there are for steam and water. We found the most complete coverage by Vasserman, Kazavchinskii, and Rabinovich [2] who have surveyed the available literature and

presented tables of values over a range of temperatures and pressures. We have used their tabular values of viscosity and thermal conductivity as the basis of our database for dry air. We have also used their recommended polynomial adjustment factors as a function of density to account for variations associated with pressure.

We have used the equations recommended by ASME (6) to compute the viscosity and thermal conductivity properties for water vapor. These are the same equations used in our WinSteam product.

There is little information available regarding the viscosity and conductivity of moist air. In most practical cases, the relatively small quantity of water vapor in air has a small effect on the overall transport properties, unlike the thermodynamic properties, which are greatly affected by moisture. Nonetheless, we have selected a method to account for the effects of moisture based on kinetic theory as presented by Hirshfelder, Curtis and Bird [4].

The equation for viscosity of a binary mixture is as follows:

$$1/\eta = \frac{X_\eta + Y_\eta}{1 + Z_\eta}$$

where

η = viscosity of the mixture

$$X_\eta = \frac{x_a^2}{\eta_a} + \frac{2x_a x_w}{\eta_{aw}} + \frac{x_w^2}{\eta_w}$$

$$Y_\eta = \frac{3}{5} A_{12}^* \left[\frac{x_a^2}{\eta_a} \left(\frac{M_a}{M_w} \right) + \frac{2x_a x_w}{\eta_a} \left(\frac{(M_a + M_w)^2}{4M_a M_w} \right) \left(\frac{\eta_{aw}^2}{\eta_a \eta_w} \right) + \frac{x_w^2}{\eta_w} \left(\frac{M_w}{M_a} \right) \right]$$

$$Z_\eta = \frac{3}{5} A_{12}^* \left[x_a^2 \left(\frac{M_a}{M_w} \right) + 2x_a x_w \left[\left(\frac{(M_a + M_w)^2}{4M_a M_w} \right) \left(\frac{\eta_{aw}}{\eta_a} + \frac{\eta_{aw}}{\eta_w} - 1 \right) \right] + x_w^2 \left(\frac{M_w}{M_a} \right) \right]$$

η_a = viscosity of dry air at the specified pressure and temperature

η_w = viscosity of water vapor at the specified pressure and temperature

$$\eta_{aw} = C_1 \frac{\sqrt{2M_a M_w T / (M_a + M_w)}}{\sigma_{aw}^2 \Omega_{12}^{(2,2)*}(T_{aw}^*)} \text{ and } C_1 = 266.93E-7$$

σ_{aw} = potential function parameter for mixture adjusted for one polar molecule

$\Omega_{12}^{(2,2)*}$ = transport property integral as a function of T^* , the reduced temperature

A_{12}^* = function of reduced temperature

In a similar manner, the equations for thermal conductivity of moist air is as follows:

$$1/\lambda = \frac{X_\lambda + Y_\lambda}{1 + Z_\lambda}$$

where,

λ = thermal conductivity of the mixture

$$X_\lambda = \frac{x_a^2}{\lambda_a} + \frac{2x_a x_w}{\lambda_{aw}} + \frac{x_w^2}{\lambda_w}$$

$$Y_\lambda = \frac{x_a^2}{\lambda_a} U^{(1)} + \frac{2x_a x_w}{\lambda_{aw}} U^{(Y)} + \frac{x_w^2}{\lambda_w} U^{(2)}$$

$$Z_\lambda = x_a^2 U^{(1)} + 2x_a x_w U^{(Y)} + x_w^2 U^{(2)}$$

$$U^{(1)} = \frac{4}{15} A_{12}^* - \frac{1}{12} \left(\frac{12}{5} B_{12}^* + 1 \right) \frac{M_a}{M_w} + \frac{1}{2} \frac{(M_a - M_w)^2}{M_a M_w}$$

$$U^{(2)} = \frac{4}{15} A_{12}^* - \frac{1}{12} \left(\frac{12}{5} B_{12}^* + 1 \right) \frac{M_w}{M_a} + \frac{1}{2} \frac{(M_w - M_a)^2}{M_a M_w}$$

$$U^{(Y)} = \frac{4}{15} A_{12}^* \left(\frac{(M_a + M_w)^2}{4M_a M_w} \right) \frac{\lambda_{aw}^2}{\lambda_a \lambda_w} - \frac{1}{12} \left(\frac{12}{5} B_{12}^* + 1 \right) \frac{5}{32 A_{12}^*} \left(\frac{12}{5} B_{12}^* - 5 \right) \frac{(M_a - M_w)^2}{M_a M_w}$$

$$U^{(Z)} = \frac{4}{15} A_{12}^* \left[\left(\frac{(M_a + M_w)^2}{4M_a M_w} \right) \left(\frac{\lambda_{aw}}{\lambda_a} + \frac{\lambda_{aw}}{\lambda_w} \right) - 1 \right] - \frac{1}{12} \left(\frac{12}{5} B_{12}^* + 1 \right)$$

λ_a = Thermal conductivity of dry air at the specified pressure and temperature

λ_w = Thermal conductivity of water vapor at the specified pressure and temperature

$$\lambda_{aw} = C_2 \frac{\sqrt{T(M_a + M_w)/2M_a M_w}}{\sigma_{aw}^2 \Omega_{12}^{(2,2)*}(T_{aw}^*)} \text{ and } C_2 = 1989.1 \text{E-7}$$

B_{12}^* = function of reduced temperature

4. ACCURACY

4.1 ACCURACY OF CALCULATIONS

Thermodynamic properties for dry air calculated by **@Air** have been checked against the values published by NBS [1]. As shown on Exhibits 5.1 through 5.4, the calculated values show excellent agreement with the source data throughout most of the valid range. Some small differences can be observed at low temperatures and high pressures. This is due to the limitations of using a third order virial equation of state. Even so, the maximum error is less than 0.3% for thermodynamic properties and 3.17% for specific heat.

Another smaller difference is shown in the compressibility factor between 1500 °K and 2000 °K. This is due to the dissociation of Nitrogen and Oxygen at these temperatures. This error is less than 0.02%.

The tables show some differences in enthalpy, entropy and specific heat occurring at 850 °K and growing with temperature. This initially, was thought to be attributed to dissociation, but this was dismissed for two reasons. First, dissociation effects were not included below 1500 °K in reference 1. Second, the error is much greater than what can be attributed to dissociation above 1500 °K.

Further examination of the data tables suggests that the tables in reference 1 are in error. One would expect the thermodynamic properties to approach the ideal gas properties as the pressure is reduced to zero. While this is the case for temperatures up to 800 °K, it is not the case above 800 °K. Curiously, at 800 °K, the tables in reference 1 change from a temperature increment of 10 °K to 50 °K at the point where the error begins. Perhaps this change of temperature increment was not handled properly.

Comparison of data from Vasserman et al [2] in the temperature range from 850 °K to 1300 °K supports the conclusion that the tables from NBS [1] are in error. Unfortunately, the tables from Vasserman et al [2] does not contain data for temperatures above 1300 °K.

Moist air properties are compared against values published by ASHRAE [9] in Exhibits 5.5 – 5.7, which show excellent agreement. It should be noted that there are small differences in the saturated humidity ratio between *DeskTop Air* and ASHRAE, which are attributed to the different models used as explained in the section on basis of calculations.

Some of the table data was generated using the **@Air** functions for convenience. They use the exact same function library as used in *DeskTop Air*.

Exhibit 5.8 plots the enhancement factors from **@Air** and ASHRAE with the original experimental data from Goff. This clearly shows that the model used by **@Air** provides better agreement with the original experimental data than the model used by ASHRAE. Since the enhancement factor is the basis for calculating saturated humidity ratio, we place a higher confidence on the saturated humidity ratio calculated by **@Air**.

**COMPARISON OF RESULTS WITH NBS [1] DATA
EXHIBIT 5.1 - COMPRESSIBILITY OF DRY AIR**

Temperature Range		Pressure					
From	To	1 atm		10 atm		40 atm	
deg K	deg K	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error
180	250	0.001%	0.002%	0.019%	0.028%	0.125%	0.279%
260	300	0.001%	0.001%	0.005%	0.008%	0.009%	0.014%
310	350	0.001%	0.001%	0.003%	0.003%	0.009%	0.013%
360	400	0.000%	0.001%	0.003%	0.004%	0.002%	0.004%
410	500	0.001%	0.001%	0.003%	0.004%	0.010%	0.013%
510	600	0.000%	0.001%	0.002%	0.003%	0.012%	0.013%
610	700	0.001%	0.001%	0.001%	0.002%	0.008%	0.010%
710	800	0.000%	0.001%	0.001%	0.001%	0.004%	0.006%
850	1450	0.000%	0.001%	0.001%	0.002%	0.002%	0.004%
1500	2000	0.004%	0.016%	0.004%	0.006%	0.004%	0.010%

**COMPARISON OF RESULTS WITH NBS [1] DATA
EXHIBIT 5.2 - ENTHALPY OF DRY AIR**

Temperature Range		Pressure					
From	To	1 atm		10 atm		40 atm	
deg K	deg K	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error
180	250	0.00%	0.01%	0.03%	0.12%	0.13%	0.26%
260	300	0.00%	0.00%	0.00%	0.01%	0.04%	0.07%
310	350	0.00%	0.00%	0.00%	0.01%	0.01%	0.01%
360	400	0.00%	0.00%	0.01%	0.01%	0.01%	0.01%
410	500	0.00%	0.00%	0.00%	0.01%	0.01%	0.01%
510	600	0.00%	0.00%	0.00%	0.00%	0.01%	0.01%
610	700	0.00%	0.00%	0.00%	0.00%	0.01%	0.01%
710	800	0.00%	0.00%	0.00%	0.00%	0.01%	0.01%
810	1450	* 0.03%	* 0.09%	* 0.03%	* 0.09%	* 0.03%	* 0.10%
1500	2000	**	**	**	**	**	**

**COMPARISON OF RESULTS WITH NBS [1] DATA
EXHIBIT 5.3 - ENTROPY OF DRY AIR**

Temperature Range		Pressure					
From	To	1 atm		10 atm		40 atm	
deg K	Deg K	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error
180	250	0.00%	0.00%	0.01%	0.02%	0.02%	0.05%
260	300	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%
310	350	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%
360	400	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
410	500	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
510	600	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
610	700	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
710	800	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
850	1450	0.00%	0.01%	0.00%	0.00%	0.01%	0.01%
1500	2000	**	**	**	**	**	**

**COMPARISON OF RESULTS WITH NBS [1] DATA
EXHIBIT 5.4 - SPECIFIC HEAT OF DRY AIR**

Temperature Range		Pressure					
From	To	1 atm		10 atm		40 atm	
deg K	deg K	Avg Error	Max Error	Avg Error	Max Error	Avg Error	Max Error
180	250	0.04%	0.11%	0.35%	1.04%	1.05%	3.17%
260	300	0.00%	0.00%	0.05%	0.06%	0.29%	0.38%
310	350	0.00%	0.01%	0.02%	0.03%	0.10%	0.17%
360	400	0.00%	0.00%	0.00%	0.01%	0.02%	0.03%
410	500	0.00%	0.00%	0.01%	0.01%	0.04%	0.06%
510	600	0.00%	0.00%	0.01%	0.01%	0.03%	0.04%
610	700	0.00%	0.00%	0.00%	0.01%	0.01%	0.02%
710	800	0.00%	0.00%	0.00%	0.02%	0.01%	0.04%
850	1450	* 0.47%	* 0.07%	* 0.47%	* 1.37%	* 0.49%	* 1.40%
1500	2000	**	**	**	**	**	**

Notes: *, ** - Questionable reference data.

**COMPARISON OF RESULTS WITH ASHRAE [9] & NBS [1]
EXHIBIT 5.5 - SPECIFIC VOLUME**

Temp ° F	Dry Air at 1 atm ft ³ /lbm			Saturated Moist Air at 1 atm ft ³ /lbm of Dry Air	
	NBS	@Air	ASHRAE	@Air	ASHRAE
-80	9.556	9.554	9.553	9.554	9.553
-70	9.809	9.807	9.807	9.807	9.807
-60	10.062	10.061	10.060	10.061	10.06
-50	10.316	10.314	10.313	10.314	10.314
-40	10.569	10.567	10.567	10.568	10.568
-30	10.822	10.820	10.820	10.823	10.822
-20	11.075	11.073	11.073	11.078	11.078
-10	11.328	11.326	11.326	11.335	11.335
0	11.581	11.579	11.579	11.594	11.594
10	11.834	11.832	11.832	11.857	11.857
20	12.087	12.085	12.085	12.127	12.127
30	12.340	12.338	12.338	12.406	12.406
40	12.592	12.591	12.591	12.696	12.696
50	12.845	12.844	12.844	13.001	13.001
60	13.098	13.096	13.096	13.329	13.329
70	13.351	13.349	13.349	13.688	13.688
80	13.604	13.602	13.602	14.089	14.089
90	13.856	13.854	13.855	14.547	14.547
100	14.109	14.107	14.107	15.083	15.084
110	14.361	14.360	14.360	15.727	15.727
120	14.614	14.612	14.613	16.519	16.519
130	14.867	14.865	14.865	17.520	17.52
140	15.119	15.118	15.118	18.826	18.825
150	15.372	15.370	15.370	20.589	20.589
160	15.624	15.623	15.623	23.082	23.082
170	15.877	15.875	15.875	26.835	26.834
180	16.130	16.128	16.128	33.037	33.037
190	16.382	16.380	16.381	45.043	45.042
200	16.635	16.633	16.633	77.426	77.426

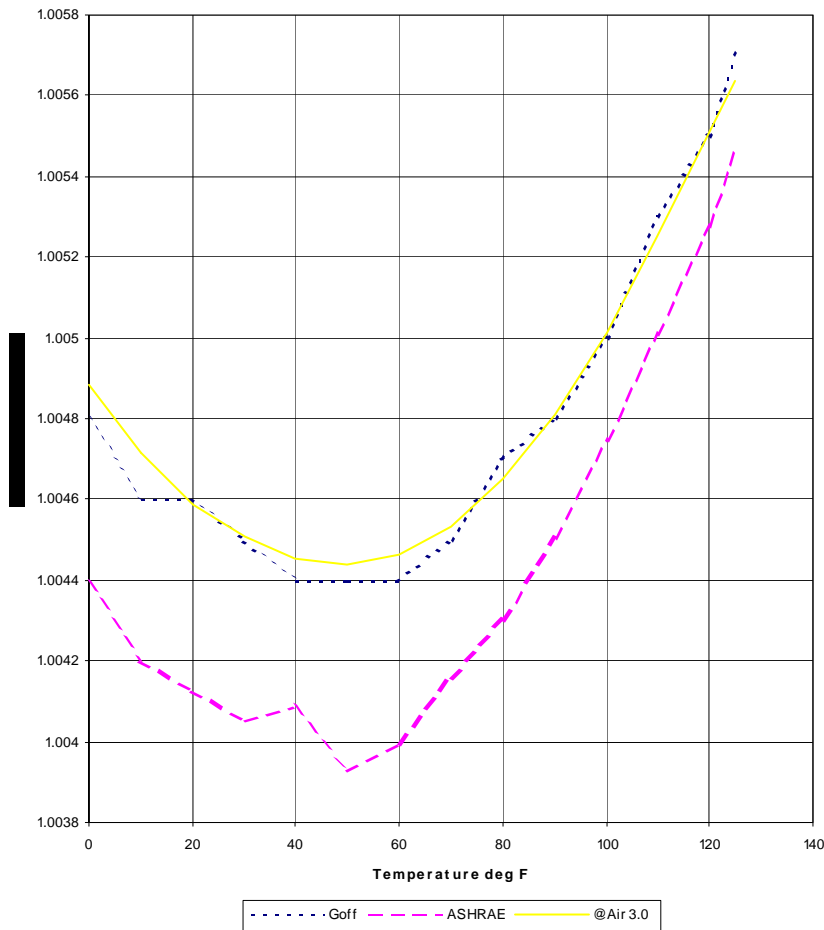
**COMPARISON OF RESULTS WITH ASHRAE [9] & NBS [1]
EXHIBIT 5.6 - ENTHALPY**

Temp ° F	Dry Air at 1 atm Btu/lbm			Saturated Moist Air at 1 atm Btu/lbm of Dry Air	
	NBS	@Air	ASHRAE	@Air	ASHRAE
-80	-19.217	-19.218	-19.221	-19.213	-19.215
-70	-16.815	-16.814	-16.806	-16.803	-16.817
-60	-14.412	-14.410	-14.414	-14.388	-14.392
-50	-12.009	-12.007	-12.011	-11.964	-11.968
-40	-9.606	-9.605	-9.609	-9.522	-9.526
-30	-7.203	-7.203	-7.206	-7.050	-7.053
-20	-4.802	-4.802	-4.804	-4.525	-4.527
-10	-2.401	-2.401	-2.402	-1.914	-1.915
0	0.000	0.000	0.000	0.836	0.835
10	2.401	2.401	2.402	3.803	3.804
20	4.802	4.803	4.804	7.106	7.107
30	7.203	7.205	7.206	10.916	10.917
40	9.606	9.606	9.609	15.233	15.233
50	12.009	12.009	12.012	20.307	20.306
60	14.412	14.412	14.415	26.470	26.467
70	16.815	16.815	16.818	34.101	34.097
80	19.218	19.218	19.222	43.706	43.701
90	21.622	21.622	21.626	55.959	55.951
100	24.027	24.027	24.031	71.770	71.761
110	26.432	26.431	26.436	92.397	92.386
120	28.837	28.836	28.842	119.628	119.612
130	31.244	31.244	31.249	156.095	156.076
140	33.652	33.652	33.656	205.849	205.824
150	36.060	36.059	36.064	275.516	275.49
160	38.469	38.468	38.474	376.760	376.737
170	40.878	40.877	40.884	532.293	532.256
180	43.289	43.288	43.295	793.156	793.166
190	45.703	45.700	45.707	1303.287	1303.321
200	48.120	48.114	48.121	2688.073	2688.205

**COMPARISON OF RESULTS WITH ASHRAE [9] & NBS [1]
EXHIBIT 5.7 – ENTROPY**

Temp ° F	Dry Air at 1 atm Btu/lbm/°F			Saturated Moist Air at 1 atm Btu/lbm/°F of Dry Air	
	NBS	@ Air	ASHRAE	@ Air	ASHRAE
-80	-0.04589	-0.04593	-0.04594	-0.04592	-0.04592
-70	-0.03964	-0.03968	-0.03969	-0.03965	-0.03966
-60	-0.03357	-0.03359	-0.03360	-0.03354	-0.03354
-50	-0.02766	-0.02766	-0.02766	-0.02754	-0.02755
-40	-0.02189	-0.02186	-0.02187	-0.02165	-0.02166
-30	-0.01623	-0.01621	-0.01621	-0.01583	-0.01583
-20	-0.01071	-0.01068	-0.01069	-0.01001	-0.01002
-10	-0.00531	-0.00528	-0.00528	-0.00414	-0.00414
0	0.00000	0.00000	0.00000	0.00192	0.00192
10	0.00519	0.00517	0.00517	0.00832	0.00832
20	0.01024	0.01023	0.01023	0.01528	0.01528
30	0.01518	0.01518	0.01519	0.02315	0.02315
40	0.02002	0.02004	0.02004	0.03187	0.03187
50	0.02478	0.02480	0.02480	0.04192	0.04192
60	0.02945	0.02946	0.02947	0.05389	0.05389
70	0.03403	0.03405	0.03406	0.06845	0.06844
80	0.03853	0.03854	0.03855	0.08643	0.08642
90	0.04295	0.04296	0.04297	0.10896	0.10895
100	0.04729	0.04729	0.04730	0.13754	0.13752
110	0.05157	0.05155	0.05156	0.17421	0.17418
120	0.05577	0.05573	0.05575	0.22183	0.22180
130	0.05989	0.05985	0.05986	0.28460	0.28457
140	0.06394	0.06390	0.06391	0.36894	0.36890
150	0.06793	0.06788	0.06790	0.48529	0.48524
160	0.07185	0.07180	0.07181	0.65193	0.65188
170	0.07572	0.07566	0.07567	0.90433	0.90425
180	0.07951	0.07946	0.07947	1.32184	1.32183
190	0.08325	0.08320	0.08321	2.12731	2.12733
200	0.08692	0.08689	0.08690	4.28462	4.28477

**COMPARISON OF RESULTS WITH ASHRAE [9]
EXHIBIT 5.8 - ENHANCEMENT FACTORS**



**COMPARISON OF RESULTS WITH ASHRAE [9]
EXHIBIT 5.9 - SATURATED HUMIDITY RATIO**

Temp ° F	Saturated Moist Air at 1 atm			
	ASHRAE	@Air	Difference	% Error
-80	0.0000049	0.0000049	0.0000000	0.00%
-70	0.0000104	0.0000104	0.0000000	0.00%
-60	0.0000212	0.0000212	0.0000000	0.00%
-50	0.0000416	0.0000417	0.0000001	0.24%
-40	0.0000793	0.0000793	0.0000000	0.00%
-30	0.0001465	0.0001466	0.0000001	0.07%
-20	0.0002632	0.0002633	0.0000001	0.04%
-10	0.0004608	0.0004610	0.0000002	0.04%
0	0.0007875	0.0007879	0.0000004	0.05%
10	0.0013158	0.0013165	0.0000007	0.05%
20	0.0021531	0.0021541	0.0000010	0.05%
30	0.0034552	0.0034568	0.0000016	0.05%
40	0.005216	0.005219	0.000003	0.05%
50	0.007661	0.007666	0.000005	0.06%
60	0.011087	0.011094	0.000007	0.06%
70	0.015832	0.015841	0.000009	0.06%
80	0.022340	0.022352	0.000012	0.05%
90	0.031203	0.031218	0.000015	0.05%
100	0.043219	0.043238	0.000019	0.04%
110	0.059486	0.059510	0.000024	0.04%
120	0.081560	0.081592	0.000032	0.04%
130	0.111738	0.111775	0.000037	0.03%
140	0.153538	0.153585	0.000047	0.03%
150	0.21273	0.21279	0.00006	0.03%
160	0.29945	0.29951	0.00006	0.02%
170	0.43343	0.43352	0.00009	0.02%
180	0.65911	0.65917	0.00006	0.01%
190	1.10154	1.10162	0.00008	0.01%
200	2.30454	2.30460	0.00006	0.00%

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